Rayleigh Scattering Diagnostic Used to Measure Velocity and Density Fluctuation Spectra

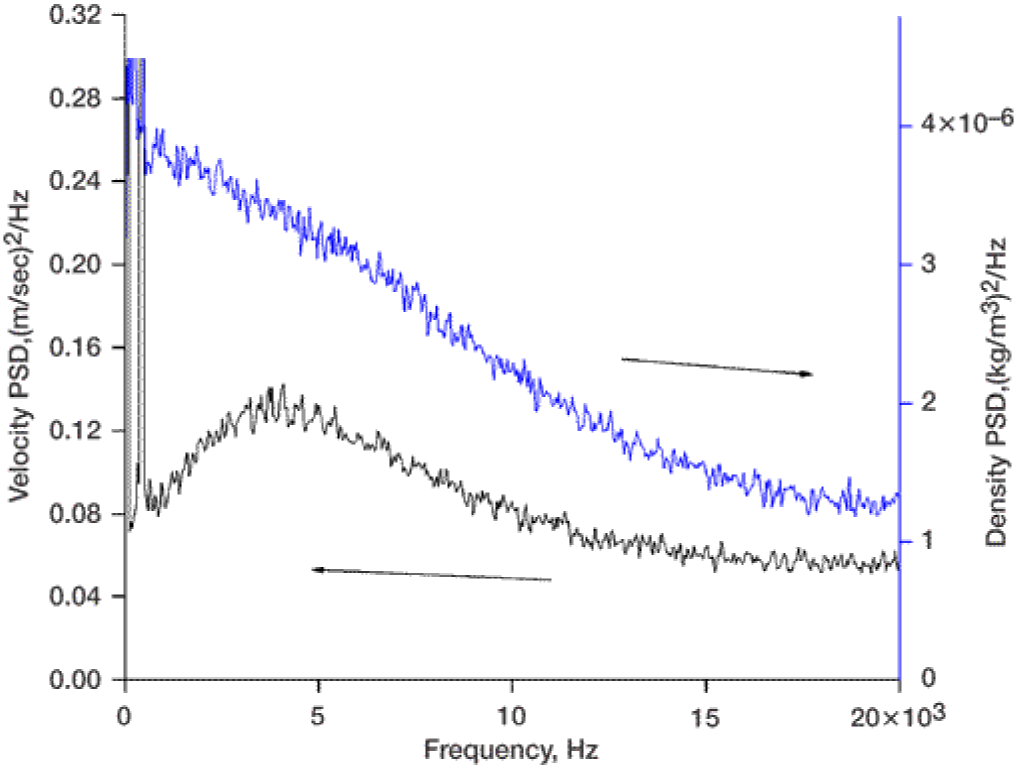
A new, molecular Rayleigh-scattering-based flow diagnostic developed at the NASA Glenn Research Center has been used for the first time to measure the power spectrum of both gas density and radial velocity components in the plumes of high-speed jets. The objective of the work is to develop an unseeded, nonintrusive dynamic measurement technique for studying turbulent flows in NASA test facilities. This technique provides aerothermodynamic data not previously obtainable. It is particularly important for supersonic flows, where hot wire and pitot probes are difficult to use and disturb the flow under study.

The effort is part of the nonintrusive instrumentation development program supporting propulsion research at the NASA Glenn Research Center. In particular, this work is measuring fluctuations in flow velocity, density, and temperature for jet noise studies. These data are valuable to researchers studying the correlation of flow fluctuations with far-field noise. One of the main objectives in jet noise research is to identify noise sources in the jet and to determine their contribution to noise generation.

The technique is based on analyzing light scattered from molecules within the jet using a Fabry-Perot interferometer operating in a static imaging mode. The PC-based data acquisition system can simultaneously sample velocity and density data at rates to about 100 kHz and can handle up to 10 million data records. We used this system to interrogate three different jet nozzle designs in a Glenn free-jet facility. Each nozzle had a 25.4-mm exit diameter. One was convergent, used for subsonic flow measurements and to produce a screeching underexpanded jet with a fully expanded Mach number of 1.42. The other nozzles (Mach 1.4 and 1.8) were convergent-divergent types. The radial component of velocity and gas density were simultaneously measured in this work.

A critical requirement in the use of molecular Rayleigh scattering for flow diagnostics is a clean, particle-free airflow. The primary air supply to the jet was filtered to remove particles. In addition, a 200-mm-diameter low-velocity filtered co-flow surrounded the jet. This co-flow was generated by an air-handling system that filtered the ambient air.

The graphs are examples of data taken along the centerline, 12 jet diameters downstream of the exit, in Mach 1.8 flow. As shown in the top graph, the velocity spectrum has a peak at about 4000 Hz. On the other hand, the density spectrum does not exhibit a definite peak, with the spectral density increasing toward low frequencies. The bottom graph shows that the density and velocity have relatively strong coherence with a phase difference of about 2.5 radians.



Power spectral densities (PSD) of velocity and density on the centerline of a Mach-1.8 supersonic free jet at a location 12 nozzle diameters downstream of the exit.

Long description of figure 1 The velocity spectrum has a peak at about 4000 Hz. The density spectrum does not exhibit a definite peak, with the spectral density increasing toward low frequencies.

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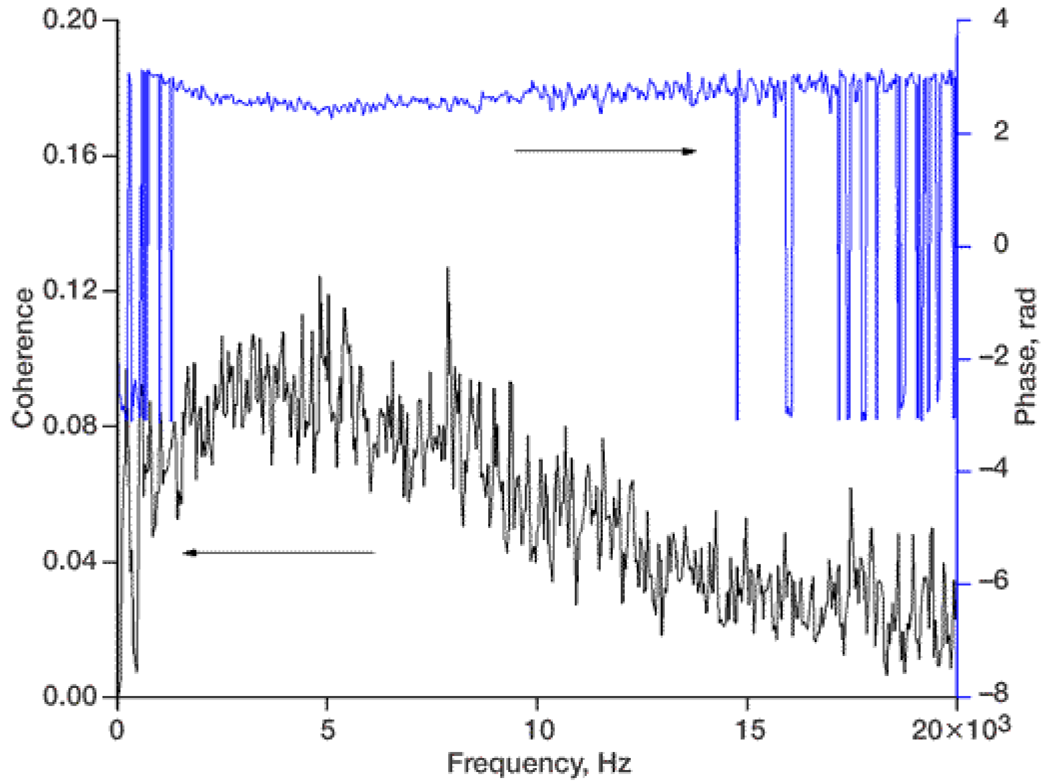

Cross spectra of velocity and density (coherence and phase) on the centerline of a Mach-1.8 supersonic free jet at a location 12 nozzle diameters downstream of the exit.
Long description of figure 2 The density and velocity have relatively strong coherence with a phase difference of about 2.5 radians.

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This instrumentation development effort is continuing, with the goal of measuring two-point space-time correlations at sampling rates to 100 kHz. In addition, simultaneous far-field acoustic measurements will be taken to allow study of correlations between the flow physics and the emitted noise.

Find out more about the research of Glenn's Optical Instrumentation Technology Branch http://www.grc.nasa.gov/WWW/OptInstr/

Reference

1. Seasholtz, Richard G.; Panda, Jayanta; and Elam, Kristie A.: Rayleigh Scattering Diagnostic for Measurement of Velocity and Density Fluctuation Spectra. AIAA-2002-0827, 2002.

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